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EUCALYPTS IN HAWAII:

a survey of practices and research programs

Russell K. LeBarron

PACIFIC SOUTHWEST
FOREST AND RANGE
EXPERIMENT STATION
BERKELEY, CALIFORNIA

FOREST SERVICE - U. S. DEPARTMENT OF AGRICULTURE

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EUCALYPTS IN HAWAII: A SURVEY OF PRACTICES AND RESEARCH PROGRAMS[1/]

By
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The systematic forest planting of eucalypts and other exotic trees in Hawaii began almost 100 years ago. According to Margolin (1911) the first commercial stand was established in 1882. It produced fuel for a sugar cane plantation in a district where supplies of native trees had been depleted. More recent research (Bryan, 1960) indicates that the first large planting occurred before 1870. Later eucalypts came to be recognized as the best all-around trees in many situations. They were grown extensively to protect denuded watersheds, as shields against the almost daily trade winds, and for the production of fuel and fence posts. On the whole, forestation for watershed protection remained the dominant aim until rather recently. Today, emphasis is directed to the use of eucalypts for lumber and veneer.

By 1910 cultural practices for the nursery propagation of eucalypts were well systematized, and 54 species had been planted. In many respects practices described by Margolin in 1911 differed little in detail from those reported by Cossitt in 1960. In principle, standards for selection of planting sites and methods for site preparation and field planting were much the same as those recommended by Zschokke in 1930. Most of these standards and methods are still in use. The major recent changes have been the substitution of heavy tractors for hand tools and animal-drawn plows in clearing sites before planting.

The total of all tree plantings in the Islands by 1960 was estimated by State Forester Walter W. Holt at about 90,000 acres, impressive for a state with a land area of only four million acres. The fraction of this planting which consisted of eucalypts is not known, but it must be more than half. Of the total trees originally planted, many were used as windbreaks and for small woodlots. The net acreage of surviving tree plantings is substantially less than the total of 90,000 acres. Some acres have been destroyed by a variety of agents, such as domestic and feral livestock, competing vegetation, and fires. Some have been harvested for fuel and other products. Probably more have been removed

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1/ Based on a report to the Second World Eucalyptus Conference, São Paulo, Brazil, August 13-26, 1961, sponsored by the Food and Agriculture Organization of the United Nations.

to clear the land for cultivation and pasture. The present net acreage of plantings, not counting windbreaks, has been estimated by U. S. Forest Service Research Center Leader R. E. Nelson at about 50,000 acres. Of this acreage, 70 percent is composed of eucalypts, broken down as follows:

Species	Acres
E. robusta	23,000
E. globulus	4,000
Other eucalypts	8,000
Total	35,000

CLIMATE AND SOILS

The Hawaiian archipelago is of comparatively recent volcanic origin. The largest and newest of the principal islands, Hawaii has active volcanoes and thus is still in the stage of building. The maximum elevation is 13,796 feet, but most of the land lies below 5,000 feet and half is below 2,000 feet.

TEMPERATURES

Temperatures in the areas suited to production of timber can be described as warm with remarkably little daily or seasonal variation. According to the Hawaii Water Authority (1959), temperatures rarely exceed 90°F., except at the driest locations, and minimums at elevations below 2,000 feet seldom drop below 55°F. The mean daily temperature at low elevations ranges from 10°F. to 18°F. The difference in mean temperature between the warmest and coldest months is only 5°F. to 8°F. In the elevational zone from 2,000 to 6,000 feet, the atmosphere is distinctly cooler, but freezing temperatures are rare. The Honaunau Forest of the Bishop Estate on the western side of the Island of Hawaii reasonably represents the kind of land that is being planted. The lowest elevation is 2,200 feet and the highest is somewhat over 4,700 feet. Carlson and Bryan report (1959) that "temperatures range from 80°F. down to 32°F." and "there may be occasional light frosts at 4,750 feet." A temperature of 26°F. has been reported at 5,100 feet elevation in the Hilo Forest Reserve (Bryan, 1947). District Forester Karl H. Korte, Maui, states that above 5,000 feet heavy frosts occur at night during the winter months.

PRECIPITATION

Rain falls abundantly throughout the islands as a whole. The median annual rainfall is 72 inches, but wide local variations exist (Hawaii Water Authority, 1959). On six of the seven largest islands the range extends from less than 18 to more than 250 inches per year. In some areas which become shrouded in cool, heavy clouds almost daily, fog drip from forest vegetation may add significantly to the total precipitation.

On Maui and Hawaii, which have the highest mountains, the greatest precipitation occurs on the easterly windward sides of the islands at relatively low elevations from 2,000 to 3,000 feet.

The rainfall in areas available and suitable for growing timber is well distributed throughout the year. Three typical examples are given to illustrate rain forest, moderately wet, and relatively dry conditions (table 1).

WIND

Wind plays a prominent part in creating the environment of the Islands. The steady, almost daily trade winds from the northeast and east blow at the rate of 10 to 18 miles per hour (Hawaii Water Authority, 1959). They bring rain and cause rain shadows on the leeward sides of the principal mountains. Trees in windward forest edges and other exposed vegetation almost all show bending and distortion from this constant force. Trade winds are the reason for extraordinarily extensive planting of tree belts to shelter cultivated fields, homes, and domestic livestock.

Violent windstorms have caused considerable damage to trees in the form of broken limbs, snapped stems, and uprooting. Such damage may become a factor of major silvicultural importance when thinning and harvesting forest crops become common. Between 1951 and 1961 four true hurricanes and a number of other tropical storms with winds up to 100 knots have pummeled the Islands, according to R. E. Nelson. Both E. robusta and E. saligna were damaged severely in some instances.

Table 1.--Rainfall in three locations in Hawaii, by months[1/]

Month	:Piihonua, Hawaii:	Hana, Maui	: Waimea, Hawaii
	Inches	Inches	Inches
January	12.18	7.81	4.86
February	16.01	6.31	4.47
March	14.88	7.64	4.95
April	17.52	9.31	4.25
May	15.18	5.24	3.12
June	13.47	3.67	2.25
July	17.62	4.53	2.99
August	20.23	5.38	3.24
September	13.81	5.33	2.24
October	13.17	4.86	2.59
November	18.63	6.34	3.67
December	19.04	8.89	5.13
Total	191.74	75.31	43.76
Basis (years)	11	32	40

1/ U.S. Department of Agriculture. Climate and Man. Yearbook of Agriculture. 1,248 pp., illus. Washington, D. C. 1941.

SOILS

Virtually all soils in Hawaii have developed from lava and volcanic cinder. Those available for timber production (not occupied for agriculture, cities, and other special purposes) are generally shallow and many are almost unbelievably rocky for highly productive timber sites. Lava solidifies into two greatly differing forms of rock--pahoehoe and aa. Pahoehoe hardens in ropy continuous masses to form relatively impervious sheets. Subsurface drainage often is poor. Aa hardens while in motion to form broken masses of porous clinkers that are highly pervious to water. Under the influence of moderate to heavy rainfall, warm temperatures, and abundant vegetation, lava rapidly weathers into fine-textured soil. Depth and drainage differ greatly within short distances in the rough, broken topography.

In areas suitable for growing timber, soils are usually acid in reaction--sometimes strongly acid. Organic litter decomposes and disappears very quickly. In most places in eucalypt forests mineral soil is covered only by litter that has fallen within less than a year.

Except in the areas of heaviest rainfall, ponds and streams that run continually are uncommon. Most water from rains penetrates into crevices in the underlying lava rock and sinks to great depths.

SPECIES

The total number of species of eucalputs that has been introduced is not known, but undoubtedly exceeds 100. Presumably many kinds have been brought in at different times without any formal records. However, chronicles of introductions by the Hawaii Forestry Division have been rather well maintained, and this organization has been instrumental in propagating and testing many species. The records and publications of the Division therefore provide the basis for most of the descriptions in this section.

CHECKLIST OF COMMON NAMES

A list of common names of many trees that have been planted in Hawaii has been prepared by the Hawaii Forestry Division and the Forest Service (Bryan and Walker, 1962). It contains 77 eucalypts (table 2). Latin names are those used by Blakely (1955).

This checklist will help standardize terminology and thus avoid uncertainty and confusion in records and reports.

Many common names have been modified from those of Australia to conform with current usage in Hawaii and with naming practices of the Forest Service. Some of these common names will appear cumbersome and strange to those who are familiar with Australian terminology, but they were necessary for several valid reasons. The Federal Trade Commission restricts the use of "mahogany," when describing wood products, to the genus Swietenia. "Gum" is ambiguous because it is a local name for several

trees in the United States. "Ash" means Fraxinus to English-speaking people in North America and "mountain-ash" is Sorbus. We can use such names as swampmahogany (E. robusta) only by using that form or by adding the Latin generic name. The problem of common names for the more widespread and abundant species--E. globulus, E. robusta, and E. saligna--has been neatly solved by calling them "bluegum eucalyptus," "robusta eucalyptus," and "saligna eucalyptus." These names will be readily understood by botanists and foresters. They undoubtedly will quickly be shortened to "bluegum," robusta," and "saligna" in spoken language and popular writing.

Table 2.--Common names proposed for 81 eucalypts in a provisional checklist[1/]

Latin epithet[2/]	Common name
alba*	ghost-tree eucalyptus
albens	whitebox eucalyptus
astringens	brown-mallet eucalyptus
baileyana	rough stringybark eucalyptus
baueriana	bluebox eucalyptus
beyeri	Beyer ironbark eucalyptus
bosistoana	coast graybox eucalyptus
botryoides*	bangalay eucalyptus
calophylla	Port Gregory eucalyptus (marri)
camaldulensis (rostrata)	river redgum eucalyptus
campanulata*	stringybark peppermint eucalyptus
camphora	camphor eucalyptus
citriodora	lemon eucalyptus
cladocalyx*	sugar-gum eucalyptus
cloeziana*	gympie messmate eucalyptus
coccifera*	peppermint-gum eucalyptus
consideniana	yertchuk eucalyptus
cornuta	yate eucalyptus
crebra (racemosa)	narrowleaf ironbark eucalyptus
dalrympleana	mountain-gum eucalyptus
deanei	Deane eucalyptus
deglupta*	Amammanit eucalyptus
delegatensis (gigantea)	alpine-ash eucalyptus
diversicolor*	karri eucalyptus
dives	blue peppermint eucalyptus
erythronema	Mt. Lindsay eucalyptus
eximia	yellow bloodwood eucalyptus
exserta	Queensland redgum eucalyptus
fastigata*	brown-barrel eucalyptus
ficifolia	scarlet flowering eucalyptus
fraxinoides	white-ash eucalyptus
globulus	bluegum eucalyptus

NOTE: See footnotes at end of table.

Table 2.--Common names proposed for 81 eucalypts in a provisional checklist[1/] — continued

Latin epithet[2/]	Common name
gomphocephala	tuart eucalyptus
goniocalyx	mountain graygum eucalyptus
grandis*	rosegum eucalyptus
guilfoylei*	yellow tingle eucalyptus
gummifera (corymbosa)	bloodwood eucalyptus
largiflorens (bicolor)*	blackbox eucalyptus
longifolia*	longleaf woolybutt eucalyptus
macrorryncha	red stringybark eucalyptus
maculata*	spotted-gum eucalyptus
maidenii	Maiden-gum eucalyptus
marginata	jarrah eucalyptus
melliodora*	yellowbox eucalyptus
microcorys	tallowwood eucalyptus
nitens*	shining eucalyptus
obliqua	messmate stringybark eucalyptus
paniculata	gray ironbark eucalyptus
pauciflora	snowgum eucalyptus
pellita*	slatyhide eucalyptus
pilularis	blackbutt eucalyptus
polyanthemos	redbox eucalyptus
populnea (populifolia)	poplarleaf eucalyptus
propinqua*	graygum eucalyptus
pulverulenta*	silverleaf eucalyptus
punctata*	leather-jacket eucalyptus
radiata*	peppermint eucalyptus
regnans	mountain-ash eucalyptus
resinifera	kinogum eucalyptus (redmahogany eucalyptus)
robertsonii*	narrow-leaf peppermint eucalyptus
robusta*	robusta eucalyptus (swamp-mahogany eucalyptus)
rubida	candlebark eucalyptus
rudis	desert eucalyptus
saligna*	saligna eucalyptus (floodedgum eucalyptus)
salmonophloia	salmon eucalyptus
salubris	gimlet eucalyptus
scabra (eugenioides)*	white stringybark eucalyptus
siderophloia	broadleaf ironbark eucalyptus
sideroxylon	red-ironbark eucalyptus
sieberiana	silvertop eucalyptus
stellulata	olive-green eucalyptus
stuartiana (bridgesiana)	apple-box eucalyptus
tessellaris	Moreton-Bay eucalyptus
tereticornis (umbellata)	forest redgum eucalyptus

NOTE: See footnotes at end of table.

Table 2.--Common names proposed for 81 eucalypts in a provisional checklist[1] — continued

Latin epithet[2]	Common name
tetraptera	fourwing eucalyptus
torelliana*	cadagi eucalyptus
torquata	flower coral eucalyptus
triantha (acmenioides)*	triantha eucalyptus
viminalis	manna eucalyptus
wandoo	wandoo eucalyptus
woollsiana	Hanow leaf-box eucalyptus

1/ Based on Bryan, L. W., and Walker, Clyde M. A provisional checklist of some common native and introduced forest plants in Hawaii. U. S. Forest Serv. Pacific Southwest Forest and Range Expt. Sta. Misc. Paper 69. 36 pp. Berkeley, Calif. 1962.

2/ Species marked with an asterisk are included in the collection at the Waiakea Tree Planting Experimental Area which is described in the section entitled Arboretum.

COMPARISON WITH OTHER TREES

Economically, the native trees of Hawaii do not offer exceptionally serious competition to the more promising eucalypts. Among these native species, only two are both widespread and abundant, koa (Acacia koa) and ohia (Metrosideros collina). Koa grows to rather large size and produces good quality hardwood of high density that has figure and color suitable for furniture, veneer, and handcraft articles. Its form often is poor and per-acre yields are not high. Some foresters suspect that if koa is protected and managed, it may perform better than has been generally assumed from the evidence supplied by mismanaged wild forests. Ohia is very widespread and much more abundant than koa. The wood is objectionably hard and sawing and seasoning are difficult. Owing to poor form, yields are exceedingly low. Many stands of ohia are no more than shrubs.

Introduced trees of other genera offer most of the competition to eucalypts for use in planting, either for wood products or other purposes. A vast number will grow in Hawaii. The forest policy makers of Hawaii are faced by a rather strange but serious dilemma--too many promising species from which to choose! These include trees of such diverse origins and kinds as Tectona, Swietenia, Sequoia, Araucaria, Fraxinus, Acacia, and subtropical and temperate zone species of Pinus.

The utility of various species suitable for Hawaii, both eucalypts and others, has received a fair amount of study. The reports of studies cited in this section are based largely but not wholly upon wood grown in Hawaii and upon the economic situation there.

The smooth-barked tree in the center is a Eucalyptus saligna, diameter 23 inches, height 160 feet. Trees with darker bark are Eucalyptus microcorys. These eucalypts on Honaunau Forest, Bishop Estate, Hawaii are 23 years old.

In 1952 Wold announced the results of testing 36 species including 9 eucalypts. He pointed out that any substantial use in the near future must be based upon E. robusta because of the abundance of this species. He ranked it "fairly easy" in milling, and "not serious" in checking and warping. In 1958 Wold analyzed eight species, including two natives—koa and ohia—for lumber production. Based upon a total possible score of 60 for various characteristics of growth, log qualities, and lumber qualities, the eight species were scored as follows:

Species	Score
Metrosideros collina (polymorpha) (ohia)	14
Acacia koa (koa)	20
E. robusta	33
E. saligna	31
Grevillea robusta	33
Fraxinus uhdei	34
Toona ciliata var. australis	36
Cedrela odorata	35

The high ranking of eucalypts results partly from their large potential yield per acre. High yield is, of course, a widely known characteristic of the genus that has been reported around the world. It is advantageous for reducing logging costs and for maximizing production from the land.

The requirements for timber products in Hawaii have been investigated by Smith (1960). He indicated that climate and construction methods place a premium on strength, appearance, and durability of lumber. For other wood products, requirements are about the same as in other parts of the United States. He pointed out that the Forest Products Laboratory has made good face-grade veneer from E. robusta and that this species is well suited to those applications requiring high strength.

Promising fields for use of sawtimber-size eucalypts in Hawaii lie in plywood and the so-called "factory-type" lumber for cabinet work, furniture, and flooring. Neither now nor in the near future will they be able to compete successfully for structural purposes on a major scale with the abundant, high grade, lighter weight, and easily worked softwoods from the Pacific Coast of North America. At present, small quantities of eucalypts, chiefly E. robusta, are being successfully manufactured and marketed for such products as flooring, furniture wood, wall panels, interior trim, shipping pallets, cross arms for telephone and electricity transmission line poles, and stakes used in irrigation systems.

Physical and mechanical properties of E. robusta and several other woods grown in Hawaii have been studied by the Forest Products Laboratory and described by Youngs (1960). His report provides detailed information on these properties and makes comparisons with properties of other Hawaii-grown woods and United States mainland species. He pointed out that the high shrinkage and interlocked grain of Hawaii-grown E. robusta lead to serious problems in drying.

The Forest Products Laboratory has studied pulping and paper-making qualities of eucalypts in considerable detail, although not with Hawaii-grown wood (1958; Keller, Kingsbury, and Fahey, 1958). From these investigations and experience and research elsewhere the pulping properties of eucalypts are rather well understood. The genus appears to have considerable use for pulp products. But wood pulp is not likely to become a major objective of timber production in Hawaii in the near future. The relatively limited local market could not absorb the whole output of a large, efficient, modern pulp plant. In national and international trade a wood pulp mill in Hawaii probably could not compete with other producers.

In form and strength eucalypts are well adapted for fence posts. Strohman (1957) has reported on wood preservative treatment of eucalypts for this purpose.

The usefulness of Hawaii eucalypts in comparison with other genera for wood products is fairly well understood. Major disadvantages of the eucalypts are weight, hardness, and problems of drying. Major advantages are (a) the presence of a considerable supply of merchantable size material of comparatively uniform size and quality that will continue to increase

in the immediate future; (b) good quality of the logs with respect to straightness, diameter, and freedom from limbs; (c) high yields per acre which result in reduced logging costs.

Eucalypts excel many, although not all, other trees in Hawaii in their ability to overtop and quickly outgrow competing vegetation. Silviculturally this is a very important advantage in a climate where many kinds of grasses, lianas, shrubs, and trees spring up quickly on denuded soil. Some species of eucalypts attain heights of 12 to 18 inches within 6 weeks after planting, several feet within 12 months, and more than 10 feet in 24 months. Such trees require relatively little or no weeding if planted on freshly cleared land. Slower starting species may need to be weeded several times. In many instances this rapid, almost explosive juvenile growth undoubtedly has caused eucalypts to be planted in preference to slower starters that produce more valuable wood, such as teak, or that may produce more cubic volume per acre, such as California redwood.

Eucalypts of better commercial utility for lumber are not equally well adapted to all planting sites. For example, on relatively arid exposed tracts on Molokai, certain pines, such as P. elliottii and P. taeda, appear more promising, and are favored in the current planting program.

CURRENT FOREST PROGRAM

"Protection of watersheds has been the keystone of Hawaii's forestry program for over 75 years," the Hawaii Forestry Research Planning Committee noted in a report (1960). But during the past decade awareness has been

Eucalyptus robusta logs at the sawmill of Hawaiian Fernwood, Ltd., Hilo, Hawaii.

growing that the Islands have good prospects for producing timber. Bryan reported in 1952 that the Island of Hawaii alone had some 30 million board feet of timber in planted stands, of which more than half were eucalypts (mainly E. robusta). He predicted that within a few years about 100 million board feet would be available there.

In 1956 Associate Territorial Forester L. W. Bryan and Myron Wold of Hawaiian Fernwood, Ltd., were sent by the Board of Commissioners of Agriculture and Forestry to New Zealand and Australia to investigate forestry and timber use techniques. Their report described the growth and use of eucalypts and trees of other genera in those countries and noted practices which they believed could be adopted in Hawaii.

Interest has grown rapidly since 1956 and the program of forestation has been accelerated. A good start has been made cooperatively by the Hawaii Forestry Division and the Forest Service to inventory forest resources and to conduct scientific research in wood properties and uses, watershed management, and forest plantation culture.

The Forestry Division has a 5-year planting plan for the Forest Reserves covering the period July 1, 1961 to June 30, 1966. It provides for a program to plant 2,850 acres per year with approximately 1.7 million trees at an average annual cost of $194,000.[2/] The plan for a representative year, July 1, 1963 to June 30, 1964, is as shown in the following tabulation:

Island	Number of acres	Number of trees	Cost
Hawaii	1,300	585,000	$ 76,500
Maui	500	291,000	29,000
Molokai	500	427,500	27,000
Kauai	500	350,000	45,000
Oahu	50	29,000	6,000
Total	2,850	1,682,500	183,500

For the entire five-year program 8.4 million trees will be used to afforest 14,250 acres. Approximately 20 percent of the trees, 1.69 million, are eucalypts:

Species	Number
E. saligna	980,000
E. pilularis	150,000
E. paniculata	290,000
E. sideroxylon	140,000
R. robusta	130,000
Total	1,690,000

2/ In addition, about 300,000 trees per year are to be produced in State nurseries for use on privately conducted tree planting projects.

The recent re-evaluation of the forest planting program, especially the greater emphasis upon timber production, has caused striking changes both in the choice of species of eucalypts and in the number of species to plant. In the earliest private plantings, E. globulus was widely grown. A little later E. robusta was planted extensively by the Forestry Division because it was well adapted to certain habitats where forest cover was wanted. As a result the bulk of the presently merchantable eucalypts are of the latter species. In the new program, E. saligna exceeds the total of all other eucalypts and E. robusta has been reduced to only 8 percent. The Division plans to plant eucalypts mainly on habitats that it does not consider as favorable for more valuable timber species.

The number of species has also been greatly reduced. From July 1, 1956 to June 30, 1959, the Board of Commissioners of Agriculture and Conservation reported that 38 species and 1 variety of eucalypts had been planted on Forest Reserves.[3/] Some of these 39 eucalypts were planted in very small numbers for purposes of testing, but the reduction from 39 to 5 is nonetheless significant. Under the new program, the number of kinds to be planted was reduced partly to concentrate upon the more promising timber species and partly to simplify future use.

CULTURE

NURSERY PROPAGATION

Nursery propagation techniques for eucalypts in Hawaii are much the same as those in several other regions of the world and thus require little comment or special explanation. The seeds are sown in small, shallow, wooden trays in sterilized soil which contains a rather high percentage of sand and organic material. Seedlings are transplanted into similar trays at a density of about 30 per square foot when about 6 weeks old. After being shaded for 7 to 10 days, these trays are placed on raised platforms in full sunlight. The trees are ready to field plant within a few months. They are carried to the planting sites in the transplant trays and are removed with small blocks of soil immediately before planting.

Nematoda are sometimes a serious nursery pest. To control them, careful sterilization of the soil by steaming or fumigation is necessary.

In April 1959, Bryan and Carlson tested the bare-root planting of E. saligna. One thousand seedlings were packed in moss and shipped to Honaunau Forest. The roots were treated with a growth hormone (kind not stated), and planted at once. Twenty-five months later, 451 of the trees were alive (45 percent). The tallest one had reached 34 feet in height and the average, 10 feet.

3/ "Forest Reserves" include much privately owned land that the owners have surrendered to the State for a predetermined number of years. This land is exempted from taxation during the term of the agreement.

On December 1, 1960, District Forester Karl H. Korte, Maui, and F. M. Cossitt of the Forest Service started a small experiment in bare-root storage and planting of E. saligna. Transplants, age 5 months, were removed from trays and subjected to four combinations of baling and defoliation treatments and stored at air temperature in a lath house. Portions of the trees from the same trays were left undisturbed in the soil for a check on the usual covered-root method. Half of the stored bare-root trees and check trees were field planted after 7 days and the remainder after 14 days. Survival was counted approximately 4½ months later on May 2, 1961. The following results were reported to this Station:

Treatment	Percent survival[4/]	
	Stored 7 days	Stored 14 days
1. Roots in sphagnum moss and waterproof paper.	87	73
2. Same as #1; leaves removed by hand.	93	47
3. Same as #1; plus tops covered with polyethelene bags.	87	80
4. Same as #3; plus leaves removed.	100	100
5. Check: planted directly from nursery trays in blocks of soil.	93	100

Due to an unusual period of drought the trees had made little or no growth and conclusions could not be made at that time as to the final effect of the treatments. Recently Korte shipped 8,000 E. saligna in polyethelene bags to Honolulu, Oahu. They were reported to have arrived in apparently very good condition.

FIELD PLANTING

The major problem in field planting is to remove competing vegetation. Vegetational cover consists of many kinds and types but in almost all instances rather complete removal is desirable or essential. Although dry periods occur in some areas and may cause competition for soil moisture, vegetation should be removed mainly to eliminate shade and to prevent small trees from being overwhelmed by aggressive grasses and climbing plants. Today the crawler-type tractor with a bulldozer blade has largely replaced earlier methods of clearing. Other types of heavy land clearing and cultivating equipment are also being tried on a limited scale.

The trees are set into holes dug with various types of mattocks and other tools for digging. In the past, trees in forest plantations have been spaced from about 8 x 10 feet to as wide as 10 x 20 feet. For watershed protection wide spacing is satisfactory, but for timber production 10 x 10 feet or 8 x 12 feet should be the maximum. The latter arrangement is generally used because planting production rates are slightly higher when trees are spaced at 8-foot intervals in rows 12 feet apart.

4/ Basis: 15 trees per treatment.

Planting is possible during most months, but some places are seasonally too wet or too dry. In certain instances planting is scheduled to correspond with periods when agricultural labor is available. For example, on Honaunau Forest of the Bishop Estate trees are planted in May, June, and July, partly because this is a favorable time to plant and partly because a labor surplus exists then (Carlson and Bryan, 1959).

Ordinarily, young eucalypt plantations require no followup care except to exclude browsing animals. In some instances, aggressive vegetation must be removed once.

RELATION TO HABITAT

Based on a great many observations, Bryan (1947) prepared a table that shows his ranking of the vigor of growth of 68 eucalypts in three elevational zones--less than 2,500 feet, 2,500 to 6,000 feet, and over 6,000 feet. Vigor was ranked as "excellent," "good," "fair," "poor," and "dead." Many species were observed only in the lowest elevational zone, and some were seen only in the intermediate or highest zone. Only seven species were recorded in all three zones. Ages of the trees are not shown. Nevertheless, this is a valuable record of adaptability and relative performance.

Recently a more complete evaluation was made of the relationships of elevation, drainage, rainfall, and broad categories of soil for *E. saligna*, *E. resinifera*, *E. microcorys*, *E. umbellata*, *E. deanei*, *E. viminalis*, and *E. robusta* (Carlson and Bryan, 1959). Although expressed in relatively general terms, descriptions form an additional valuable record for the guidance of foresters.

In 1960 the Forest Service and the Hawaii Forestry Division conducted a detailed study of the growth of *E. robusta*, *E. saligna*, *Fraxinus uhdei*, and *Toona ciliata* var. *australis* on the island of Hawaii, (Pickford and LeBarron, 1960). Two 1/10-acre plots were measured for each of the two eucalypt species in eight different plantations, and one additional 1/10-acre plot was taken in each of two additional stands of *E. saligna*. These plots were located in stands where survival and stocking were moderately good or better in order to determine the potentialities of the trees in the specific habitats. Locations were chosen to sample a wide variety of habitat conditions.

	E. robusta	*E. saligna*
Elevation (range, in feet)	1,300- 2,400	1,700- 6,600
Annual rainfall (range, in inches)	75- 250	45- 250
Age (range, in years)	23- 38	21- 30
Trees per acre over 10.9" d.b.h. (range, in number)	145- 260	30- 210
Basal area per acre (range, in square feet)	222- 800	114- 365
Height of dominants (range, in feet)	93- 179	89- 174
Mean annual growth (range in feet, board measure)	500- 3,400	500- 3,800

The two eucalypts grew about equally well within the ranges of elevation and rainfall where they were found. Soil depth and soil drainage both appeared to be important though the number of plots was too small and the soil examinations were too superficial to warrant positive conclusions. The ages could not be determined at which maximum yields and highest mean annual growth occurred. The E. saligna trees were somewhat superior to the E. robusta in stem form and natural pruning. In one instance, E. robusta was seen to be aggressively invading an E. saligna stand by seeding. Some of the invaders were at least 40 or 50 feet tall.

Under tropical rain forest conditions E. robusta shows a curious condition on all major islands in Hawaii. Roots start from adventitious buds on the stem at heights of 20 to 40 feet and grow downward, usually through the bark into the soil. The lower stems of occasional E. robusta become completely encased by an interwoven mass of these aerial roots, some of them eight inches in diameter. We have been told that this does not occur in Austalia. Perhaps here is a clue that the species is a relict from a humid, tropical climate in an ancient era when aerial rooting may have been a common habit of growth.

MANAGEMENT AND HARVESTING

Considerable numbers of E. robusta have been harvested on a piecemeal basis for such special products as poles and pilings. Some stands have been cut clean and some have been cut "selectively." These cuttings have not generally been made with a silvicultural control or method in mind. Consequently in this context, "to select" means to remove trees that will serve the purpose of the cutter.

Nevertheless, past cuttings give some clues for future silvicultural management. The stumps sprout prolifically and the new shoots grow rapidly even in lightly cut stands. Some coppice shoots are severely suppressed by the faster growing ones. The weaker ones usually die, but artificial removal of all but the one best sprout per stump would be desirable. The sprouts of E. robusta apparently will provide at least two additional timber crops unless some more shade-tolerant tree becomes established as an understory and effectively bars regrowth of future sprouts. We saw one stand of E. robusta where Podocarpus cupressina had invaded very heavily. As mentioned earlier, we also observed an instance in which E. robusta had invaded E. saligna. Hence, we should anticipate that more shade-tolerant or better-adapted species will sometimes prevail over even very vigorous coppice growth within one or two rotations if seed is available, unless the invaders are eliminated.

A possibly beneficial effect of mixing two species of eucalypts was observed in connection with the growth study made in 1960 (Pickford and LeBarron). In a stand composed of alternate rows of E. saligna and E. resinifera, the E. resinifera had been completely overtopped and none had reached sawtimber size (10.9 inches d.b.h.). They appeared to have served to crowd and prune the E. saligna while the latter trees were making their principal height growth. Eventual suppression of the E. resinifera acted like a natural thinning and left room for the E. saligna to continue growing.

Foresters of the Forestry Division say that the progeny from Hawaii-grown seeds often are hybrids. Almost certainly, wherever crossable eucalypts grow together hybridization will create both problems and opportunities. In either natural seeding or artificial propagation taxonomy may become hopelessly confused in one or two tree generations. The hybrid swarms may contain both superior and inferior types.

COSTS AND RETURNS

The plan for planting and managing the privately owned and administered Honaunau Forest provides the chief source of information on costs and returns from growing eucalypts. This report (Carlson and Bryan, 1959) should be reviewed for a fuller account and explanation. It and limited data about the State planting program are the basis for most of the information in the remainder of this section. Itemized planting costs for portions of the Honaunau Forest where heavy forest cover must be cleared on aa land are:

Item		Cost per acre (1959)
Clearing		$30.00
Planting (spacing 10 x 12 feet; 363 trees per acre)		
Labor (plant 600 trees per man-day at $8)	$4.85	
Foreman (1 per 5 planters at $12)	1.46	
Forester (limited general supervision)	0.54	
Transportation (20 miles per day at $0.20 per mile)	0.48	
Trucking trees from nursery	0.14	
Total		7.47
		$37.47

The costs shown above do not include planting stock because the State provided the trees without charge. Cossitt estimated in 1960 that in a mechanized nursery with an annual production of 4.5 million trees, stock would cost about $11 to $18 per thousand. From the spacing being used on the Honaunau Forest this would amount to roughly $4 to $7 per acre. The present cost of production of stock in the State's several small non-mechanized nurseries is perhaps two to four times as much.

By way of comparison with the cost cited above for the Honaunau Forest, the estimated cost per acre in the State's five-year planting plan is about $65 per acre (Hawaii Forestry Division, 1961). However,

5/ In May 1961, Carlson revised his estimates upward to a total of $47 per acre. Principal changes resulted from reducing spacing to 10 x 10 feet (426 trees per acre) and adding a road construction cost of $5 per acre.

the costs at the Honaunau Forest and on the State Forest Reserves probably are not wholly comparable. The State's expenditures include cost of nursery stock and construction of roads to make planting sites accessible. Although roads must be charged to the appropriation for planting, they have permanent value for other purposes. Also, the State will plant almost 600 trees per acre. These differences explain much of the higher outlay. On the other hand a limited amount of prison labor will be supplied, probably at some saving to project funds.

The management plan for the Honaunau Forest estimates yields for E. robusta and E. saligna at 40,000 to 80,000 board feet per acre at 30 years conservatively. Assuming conservatively that the rotation is 35 years and that present stumpage value will be $20 per thousand board feet, then earnings per acre for deep soils and aa land were calculated as follows:

Investment in planting ($38 at 5 percent interest)	$ 210
Yield (60,000 board feet at $20 per thousand)	1,200
Gross profit for 35 years[6/]	990
Gross profit per year	28

Under the same conditions profits for Fraxinus uhdei and Toona ciliata var. australis were estimated at $35 and $39 per acre per year.

Estimates of yields and gross profits from eucalypts were also made for two other site conditions, one amounting to $30 per acre per year; the other, $19.

The management plan suggested that costs would decline and net earnings would increase after the first rotation because the stands would reproduce by sprouting.

RESEARCH

In 1957, the Hawaii Department of Agriculture and Conservation and the Forest Service entered into a cooperative agreement on forest research. Scientific direction is supplied by the Forest Service; both organizations furnish employees; and the State has taken an active part in the selection of subjects to study. This arrangement makes the services of this Station and the Forest Products Laboratory available to Hawaii. Both State and Federal agencies contribute to the financing and conduct of the research program. A research center under the direction of R. E. Nelson was established at Honolulu by this Station in 1958.

FOREST SURVEY

The first and, to date, the largest undertaking has been an inventory of forest resources. From two to four foresters have been engaged on this project. Determination of acreage of wildlands, vegetational cover types, and timber volume and growth are major primary objectives. An

6/ Taxes and costs of administration have not been deducted from gross profit.

Aerial roots are a remarkable condition manifested by Eucalyptus robusta in Hawaii. They can extend to the ground separate from the tree trunk, as shown above left. These roots can also encase the tree trunk, as shown above right.

important adjunct to the survey is the preparation of tables to measure the cubic- and board-foot contents of timber. This survey is now almost completed. When finished it will provide more accurate estimates of the acreage, volume, and quality of eucalypt forests than are now available. It will also provide volume tables specially designed for the locally grown eucalypt trees.

SILVICULTURE

One forest scientist was engaged full time on silvicultural research during 1960 and 1961. In 1962 the number was increased to three. In addition other scientists are assigned temporarily from time to time.

A few miles from Hilo at an elevation of 800 feet test plantings of many genera and species of trees have been made at the Waiakea Tree Planting Experimental Area by the Hawaii Forestry Division. Thirty eucalypts are included, of which 28 are identified by an asterisk (*) in the provisional checklist (table 2). The other two are E. salicifolia (amygdalina) and another identified only by the lot number of the collection, "11309."

The eucalypts in this arboretum were planted between August 1957 and July 1960. They are spaced 10 feet by 10 feet, and numbers range from 10 to 364 per species. Most of them are arranged in rows of 10 and generally all trees of one species are located in one or two groups. Additional trees may be planted.

The records and maps of this experimental area are quite complete. For example, they have been used to show the growth at age two years of some faster growing species and the species that did not attain an average height of 5 feet at that age (table 3). Eucalypts are well represented among the fast starters, but some of them also are included among the species that grew slowly during the first two years after outplanting.

In 1961 several small permanent growth plots were established in various locations on the Island of Hawaii for periodic remeasurement. These will supply the first information on periodic growth to guide forest managers in determining the proper time to harvest for maximum yield. The plots will also supply information on stand structure and plant succession. E. pilularis, E. saligna, E. resinifera, and E. robusta were included among the species sampled. Admittedly, the few plots that were established will supply only limited information. Ultimately many growth plots must be installed. A few spacing studies also were established to determine optimum initial stocking. For eucalypts the spacings to be tried are 8, 10, 12, and 16 feet. An experiment was also made with a mechanical tree planter on saligna eucalyptus on Molokai. Preliminary results were satisfactory. These tests may or may not include eucalypts.

Probably almost all of the eucalypts which have good potential for wood production are already present in Hawaii. However, a vast array of possibilities exists for research in genetics in the areas of hybridization, provenience, and selection of superior genotypes.

Silvicultural control of wood quality is an unexplored field. Site adaptability needs much more study. Soil deficiencies, soil depletion, and soil amendments have not been studied with respect to eucalypts and other trees. These opportunities for research greatly exceed the possibilities for finding answers quickly unless the research program is greatly accelerated.

PROTECTION

Grazing and forest fires present no serious problems today. Nor are serious parasites known to be present in growing forests. Quarantine regulations on importations are strict and well enforced, but no one knows when some serious parasite of eucalypts may slip in. As mentioned earlier, wind damage may become more severe when harvesting increases.

WOOD USES

Undoubtedly, more attention could and should be given to the study of wood properties. More urgent problems are milling and seasoning practices, development of products that are best suited to the local economic

structure, and wood preservation. In this warm humid climate, termites, boring insects, and decay organisms destroy logs and many manufactured products. A products research specialist has been assigned by the Forest Service as part of the cooperative program with the Forestry Division to conduct local studies and maintain contact with the Forest Products Laboratory.

Table 3.--Size of some trees in the Waiakea Tree Planting Experimental Area two years after outplanting[1/]

Species	Average height	Average d.b.h.	Maximum height
	Feet	Inches	Feet
Species that reached average height of 10 feet			
Casuarina cunninghamiana	15.8	3	27
Casuarina nodifolia	13.0	1 1/2	20
Eucalyptus botryoides	22.4	5 1/2	37
Eucalyptus cloeziana	12.8	1 3/4	15
Eucalyptus deglupta	17	5	27
Eucalyptus grandis	18.1	4 3/4	37
Eucalyptus pellita	14.9	4	27
Eucalyptus punctata	15.6	3 3/4	30
Eucalyptus radiata	15	3 1/2	26
Eucalyptus robusta	15.2	4 1/2	28
Eucalyptus rubida	15.5	3	27
Eucalyptus saligna	18.9	4 1/2	35
Toona ciliata var. australis	11.6	4	39
Species that reached average height of 5 feet or less			
Araucaria excelsa	3	1/2	7
Araucaria angustifolia	3.4	1/2	5
Callitris macleyana	1.24	--	3
Castanosperma australe	1.7	1/4	4
Cedrela odorata	2.6	2 1/2	10
Chamaecyparis lawsoniana	4	3/4	5
Eucalyptus largiflorens (bicolor)	4.8	1/4	8
Eucalyptus coccifera	3.8	1/4	7
Eucalyptus fastigata	2.9	1/2	6
Eucalyptus robertsonii	3	1/4	5
Eucalyptus sp. #11,309	2.8	1	10
Flindersia ifflaiana	1.9	3/4	9
Pinus palustris	1	--	1
Pinus taeda	3	1/2	4
Tectona grandis	4	1/2	12

1/ Unpublished manuscript by L. W. Bryan, undated, copy on file, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

WATERSHED MANAGEMENT

Protection of the water supply for agricultural, industrial, and domestic use is still a matter of great concern to the public and to State officials. Two scientists are now working on problems of hydrology in forests. They seek to learn how the production of usable water can be maximized. The problem partly is to insure recharging of underground water supplies; partly it is to insure delivery at surface streams and catchments. The watershed research program is interested in such aspects of forest hydrology as (a) fog drip, (b) interception of rain by vegetation, (c) use of soil moisture by vegetation, (d) water infiltration into the soil and how it is affected by vegetational cover and by logging and other land uses, and (e) causes and prevention of soil erosion. The first studies deal with soil compaction and the depletion of soil moisture by several kinds of plant cover, including eucalypts.

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